

THE NASA LEWIS STRAIN GAUGE LABORATORY - AN UPDATE

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At the 1985 HOST conference the status of the Lewis strain gauge laboratory was described. The goals were outlined, a description of the apparatus was presented, and some preliminary data were shown which demonstrated the ability of the laboratory to perform the types of tests required to characterize high temperature static strain gauges. At present the goals are unchanged, that is, to support HOST programs in the area of high-temperature static-strain measurement both in-house and through contract work.

Efforts continue in the development and evaluation of electrical-resistance strain gauges of the thin-film and small-diameter wire type. This paper presents results obtained early in 1986 on some Chinese gauges and Kanthal A-1 gauges mounted on a Hastelloy-X substrate. Also, the status of several activities currently in progress will be presented. These more recent efforts include (1) the determination of the uncertainty in our ability to establish gauge factor, (2) the evaluation of sputtered gauges that were fabricated at Lewis, (3) an investigation of the efficacy of dual-element temperature-compensated gauges when using strain-gauge alloys having large thermal coefficients of resistance, and (4) an evaluation of the practical methods of stabilizing gauges whose apparent strain is dependent on cooling rate (e.g., FeCrAl gauges).

MEASUREMENT CAPABILITY

A major characteristic of interest when using electrical resistance strain gauges is the sensitivity to strain or gauge factor. Because some early data showed excessive hysteresis, repeat tests were run to try to determine our ability to impose a known strain on a test gauge. Gauge factor determination tests use constant-moment beams as shown in figure 1. An Inconel 718 beam with four reference gauges was mounted in the bending fixture and stressed to about ± 2000 microstrain ($\mu\epsilon$) using different types of clamps, round and square edged.

Strain in the test beam is calculated from the equation:

$$e = \frac{td}{l^2}$$

where e is strain, t is thickness, d is deflection, and l is length.

The beam thickness and deflection can be measured very accurately, but, due to clamping/mounting variations, the length must be determined experimentally. Tests results between the square and round edged clamps show the rounded edge had about 35 percent less data scatter.

Figure 2 shows the variation of the effective, calculated beam length versus deflection in both tension and compression; a deflection of about 1.2 cm is equivalent to 2000 μ e. Also, a ± 1.0 percent of full-scale error band is shown. Repeated cycling to check on zero shift showed a residual $\pm 5 \mu$ e that is apparently due to hysteresis. Zero shift can be minimized by exercising the beam before taking data. All of these tests tend to show that strain calculations based on beam deflection have an uncertainty that is a small fraction of the total error budget; that is, they have an inaccuracy of less than 1 percent.

SPUTTERED GAUGES

One goal of the Lewis sensor development section has been to develop in-house capability for sputtering thin-film sensors. Eight thin-film strain gauges were recently fabricated. Four were sputtered from a FeCrAl target, the others from a PdCr target. The estimated thickness of the film is 2 μ m. Two types of lead wires were used: a 0.76-mm-diameter NiCrSi wire and a 0.025- by 0.25-mm ribbon of Pd. The leads were attached to the film with a parallel-gap welder.

The substrates were 1.1-mm-thick alumina beams similar in shape to that shown in figure 1. Alumina beams were used for several reasons - alumina is a good high-temperature material, it doesn't require an insulating layer before gauge installation, and, because advanced turbine engines will be using components of ceramics, some experience will be gained in learning to instrument nonmetallic material.

These gauges are scheduled to be tested for gauge factor determination and apparent strain tests in the near future. However, before testing, a heat treatment will be required to recrystallize the as-sputtered alloy in order to have good resistance to oxidation. In the case of the PdCr alloy, the self-protective scale of Cr₂O₃ that prevents additional oxidation may not be sufficient for long-term use, and an additional overcoat may have to be sputtered. An investigation for implementing this additional protection is in progress under UTRC contract to develop this gauge system.

TEMPERATURE COMPENSATION

Many strain-gauge alloys exhibit a large apparent strain when heated, partly due to high values of thermal coefficient of resistance (TCR). One well-known technique to minimize this effect is to install a second element of a selected material in an adjacent arm of a Wheatstone bridge. The two elements will compensate for each other over a range of temperatures.

A major effort of HOST funded research in strain measurement has been the search for a strain-gauge alloy usable to 1000 °C. The PdCr alloy developed at UTRC under NASA contract appears to have the desired characteristics of a linear, stable, repeatable resistance versus temperature relationship, but, because of a high TCR, gauges of this alloy will require a compensation element. In anticipation of this need, an experiment to learn how to achieve the compensation was performed. Two Pt8W gauges and two compensating resistors were flame sprayed over an alumina insulating layer on an Inconel 718 test beam. One gauge used a Pt wire compensating resistor, the other a Pd wire. The components were connected as shown in figure 3. Tests are currently underway to measure apparent strain versus temperature of these two gauges.

TEST RESULTS ON FeCrAl GAUGES

Two 13- by 20-cm Hastelloy-X plates were instrumented, each with two Chinese-type gauges and two Kanthal A-1 gauges. The Chinese gauges were bonded with a high-temperature ceramic adhesive. The Kanthal gauges were applied by flame-spraying an insulator onto the substrate. The Kanthal gauge was then cemented down and given another flame-sprayed overcoat. Type K thermocouples measure plate temperature. One plate will be used in an experiment on combustor liner thermal cycling; the other has been thermally cycled at zero stress in an isothermal oven to determine apparent strain.

The FeCrAl alloy used in these gauges undergoes an order-disorder effect between 400 and 600 °C, and the shape of the apparent strain curve during a heating cycle is strongly dependent on the rate of cooling of the gauges during the previous cooling cycle. Figure 4 shows data on all four gauges after a fast cooldown. A fast cooldown is defined as one traversing the critical temperature zone (600 to 400 °C) in less than 20 seconds.

If these gauges are soaked at a temperature of 700 °C for several hours, the gauge resistance will stabilize and have a repeatable value. Figure 5 shows the effect of three cooling rates on the apparent strain curves for both types of gauges. The conclusion to be drawn from figure 5 is that at 700 °C Kanthal A-1 has an apparent strain that is approximately eight times that of the alloy used in the Chinese gauges. Also, the Kanthal A-1 is much more affected by the cooling rate. For each type of gauge, the upper, middle, and lower curves represent cooling rates of 5.5, 1.0, and 0.1 K/s, respectively.

These data clearly show that, in order to use these gauges in an actual high temperature application, the following precautions must be observed: (1) in order to make a correction for apparent strain, the thermal history of the gauge must be known - or preferably controlled, (2) gauges must be soaked at 700 °C for a few hours to define the starting point, and (3) temperature excursions through the critical temperature range should be made as quickly as possible to avoid errors due to excessive drift.

The requirement for heating these gauges to 700 °C for at least 1 hour before use may preclude their use in certain applications. We will attempt to stabilize a gauge after installation by heating it with an electrical current. Test components are now being fabricated so we can explore this approach. Particular attention will be paid to the lead wire selection, attachment method, etc. If the gauges can be heated to 700 °C and held at that temperature for the proper length of time, the chance is good that when the power is shut off, the relatively large mass of the test piece will act as a heat sink to rapidly cool the gauge, resulting in a known, repeatable apparent strain curve.

CONSTANT MOMENT TEST BEAM

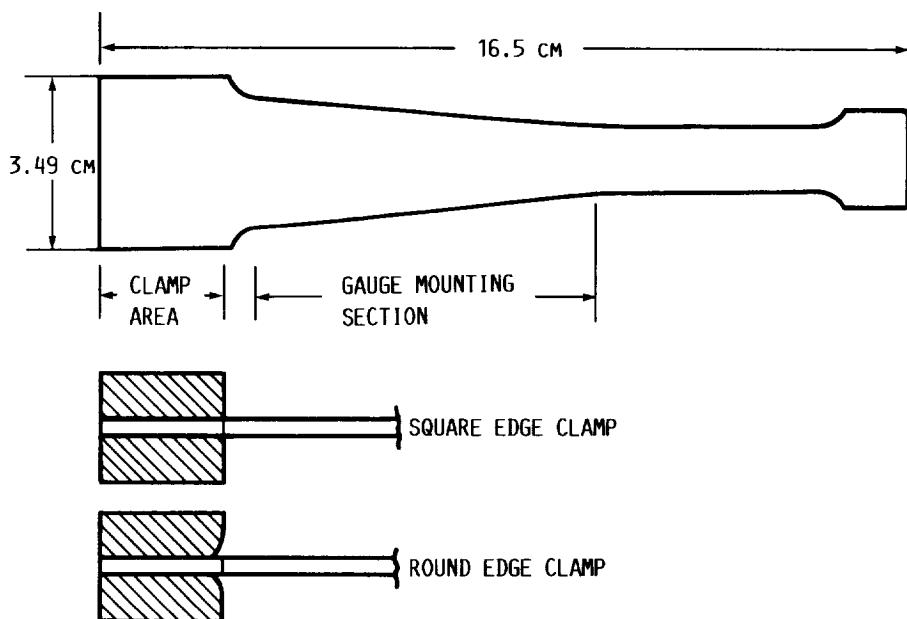


Figure 1

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EFFECTIVE BEAM LENGTH VERSUS DEFLECTION

BASED ON FOUR REFERENCE GAUGES

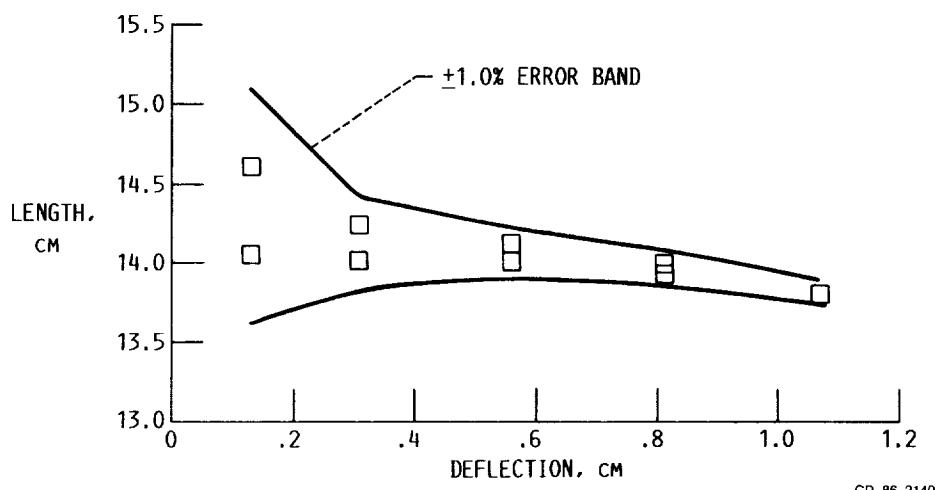
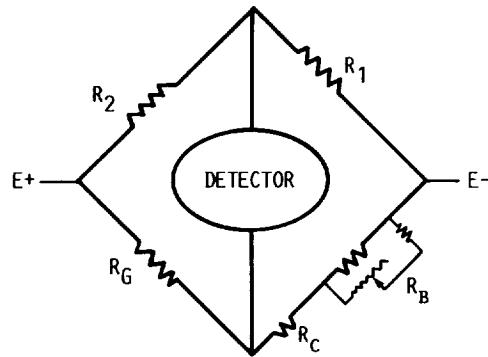


Figure 2

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BRIDGE LAYOUT FOR COMPENSATION TEST



TEMPERATURE, °C	20	700
STRAIN GAUGE RESISTANCE, R_G, Ω	104.4	144.4
COMPENSATING GAUGE RESISTANCE, R_C, Ω	14.7	37.18
BALLAST RESISTANCE, R_B, Ω	43.97	43.97

R_1 AND R_2 = BRIDGE COMPLETION RESISTORS

$$R_B = \frac{\Delta R_C}{\Delta R_G} R_G - R_C$$

CD-86-21408

Figure 3

APPARENT STRAIN VERSUS TEMPERATURE

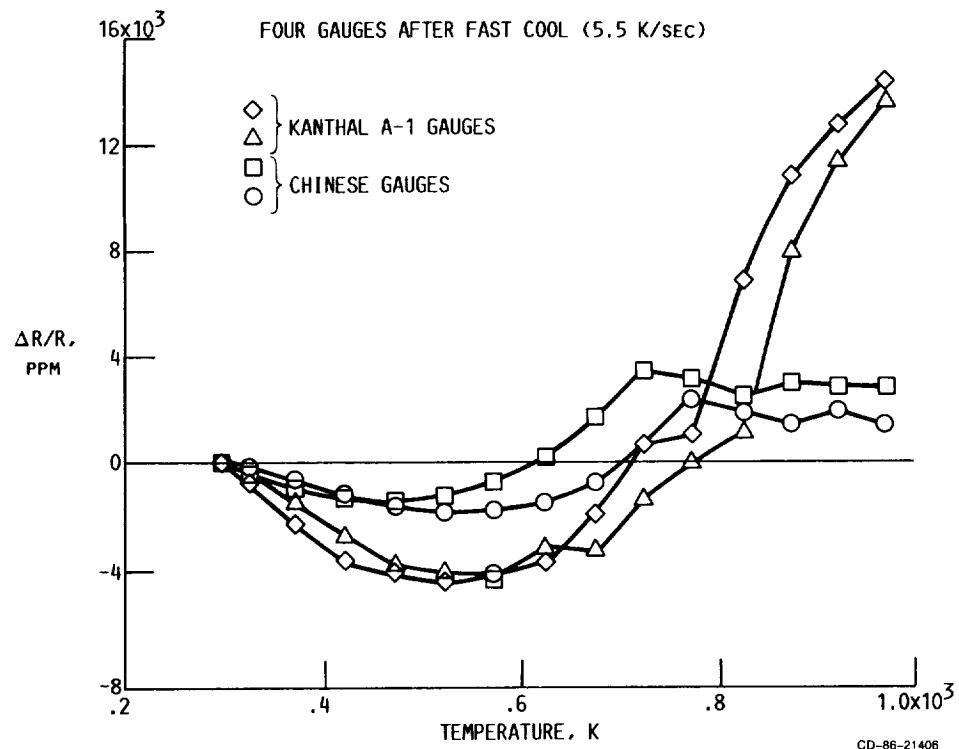


Figure 4

APPARENT STRAIN VERSUS TEMPERATURE

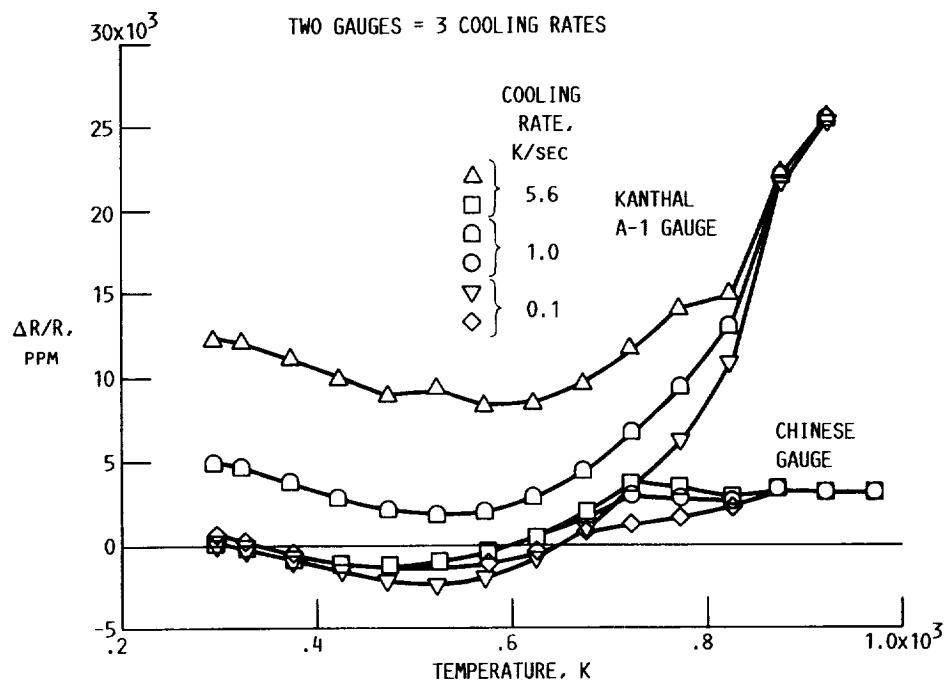


Figure 5